On the lives of extra-galactic radio sources: the first 100,000 years

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Abstract

In this paper we discuss the early phase of radio source evolution as represented by Gigahertz Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS) radio sources. Correlations between their spectral peak and angular size strongly suggest that the spectral turnovers are caused by synchrotron self absorption, and indicate that young radio sources evolve in a self similar way. We argue that the evolution of a radio source during its first 10^5 years is qualitatively very different from that during the rest of its life-time. This may be caused by the difference in the density gradient of the intra-galactic medium inside and outside the core-radius of the host galaxy.

1 Introduction

Gigahertz Peaked Spectrum (GPS) sources are characterised by a convex shaped radio spectrum peaking at about 1 GHz in frequency (O'Dea 1998). The existence of spectral turnovers in these objects implies that their radio emission is confined to very compact regions. Indeed, VLBI observations show that their radio structures are in general smaller than a few hundred parsecs (Stanghellini et al. 1997). The morphologies of GPS sources optically identified with galaxies are typically dominated by two components which are more or less equal in flux density and spectral index. Since sometimes a very compact flat spectrum component can be seen in the center, characteristic of a core, the two dominant outer components are in general interpreted as the hot-spots/mini-lobes. The two-sided morphology of these objects is very

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distinctive compared to that of compact radio sources in general. When selected from VLBI surveys, they are treated as a separate class (Wilkinson et al. 1994), and named Compact Symmetric Objects (CSO). The overlap between CSO and GPS galaxies is large and it can be assumed they form one and the same class of object. However, the overlap is not complete: orientation effects can alter both the morphology and radio spectrum in such way that the objects are not classified as CSO or GPS respectively (Snellen et al. 1998a). Furthermore, it has been claimed that some CSO do not exhibit a spectral turnover at low frequencies. If true, this would make the young nature of these particular CSOs less likely, since it implies the existence of substantial large scale radio emission. GPS sources identified with quasars, which are mostly found at high redshifts, have core-jet morphologies in general and may not be physically related to the CSO/GPS galaxies(Stanghellini et al. 1997, Snellen et al. 1998b).

Since the initial discovery of Gigahertz Peaked Spectrum (GPS) sources, it has been speculated that these are young objects (Shklovsky 1965, Blake 1970), but only recently, compelling evidence in favour of this hypothesis has been given. The strongest evidence comes from measurements of the separation velocities of the hot-spots in several GPS sources, implying dynamic ages of typically 10^3 years (see Conway, this volume). Furthermore, detailed measurements of the spectral ages of the somewhat larger Compact Steep Spectrum (CSS) sources indicate spectral ages in the range of $10^3 - 10^5$ years (see Murgia, this volume). The alternative hypothesis that GPS and CSS sources are old objects situated in a very dense environment impeding the outward motion of the jet is also less likely, since no evidence for any difference between the environments of GPS, CSS and large size radio sources has been found.

In this paper, we discuss results on the early evolution of radio sources from the investigation of three samples of faint and bright GPS and CSS galaxies: 1) The faint GPS sample selected from the WENSS survey (Snellen et al. 1998b, Snellen et al. 1998c, Snellen et al. 1999), 2) the bright GPS sample from Stanghellini et al. (1998), and 3) the CSS sample selected by Fanti et al. (1990).

2 The spectral turnovers and morphological evolution

The combination of the faint GPS sample and bright GPS and CSS samples from the literature gave a unique opportunity to investigate the relation between the spectral peak and size of young radio sources. Not surprisingly, the inverse correlation between peak frequency, ν_p, and angular size, θ, was confirmed. However, in addition, a correlation was found between the peak flux density, S_p, and angular size. The strengths and signs of these two correla-

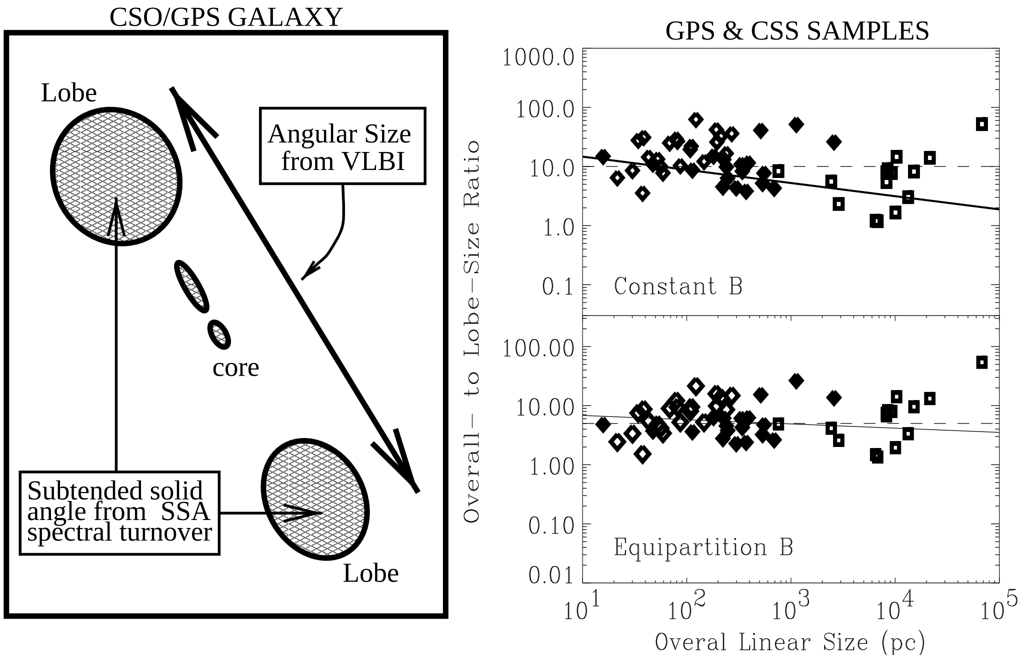

Fig. 1. (Left) A schematic view of a young radio source. The overall angular size can be determined from VLBI observations, while the sizes of the lobes can be derived from the synchrotron self-absorption turnover. (Right) The overall size to lobe size ratio in faint and bright samples of GPS and CSS galaxies, assuming a fixed- (top panel) and an equipartition magnetic field (bottom panel).

tions are exactly as expected for synchrotron self absorption (SSA), for which $\theta^2 \propto S_p B^{1/2} \nu_p^{-5/2}$, where B is the magnetic field. This strongly suggests that SSA is indeed the cause of the spectral turnovers in GPS and CSS sources, and not free-free absorption as recently proposed by Bicknell et al. (1997).

The solid angle subtended by the dominant features, the mini-lobes, determines the strength and frequency of the spectral peak (see fig 1). The angular size determined from VLBI observations, corresponds to the *overall* angular size of the object. The correlations discussed above therefore imply a constant ratio of overall size to lobe size in samples of faint and bright GPS and CSS galaxies. This indicates that young radio sources grow in a self-similar way.

The sizes derived for the lobes are slightly dependent on the magnetic field strength (see above). The ratios of the overall to lobe sizes were determined for a fixed magnetic field of 10^{-3} Gauss and for an equipartition magnetic field (Scott & Readhead 1977). The results are shown in the top and bottom panel of fig 1 respectively. The ratios, calculated using an equipartition magnetic field, do not show a trend with linear size, but they show a decline with linear size when a fixed magnetic field is used. This seems to indicate that the self-similar evolution scenario (dashed line) is better fitted (solid line) for an equipartition magnetic field than for a constant magnetic field.

3 The Luminosity evolution of radio galaxies

Several evolution models have been proposed for GPS sources, in which GPS sources subsequently evolve into CSS sources and large-scale doubles (Hodges & Mutel 1987, Fanti et al. 1995, Readhead et al. 1996, O'Dea & Baum 1997). In these models, the age ratio of large size objects to GPS sources is typically $\sim 10^3$. The much larger fraction (say 10%) of GPS in radio surveys therefore implies that young radio sources have to substantially decrease in radio luminosity (a factor ~ 10) when evolving to large scale radio sources. Readhead et al. (1996) find from their CSO statistics that the luminosity evolution from 10 pc to 150 Kpc is consistent with a single power-law decrease. This in contrast to O'Dea & Baum (1997) who find that the number of GPS and CSS sources per bin of log projected size is constant from 100 pc to 6 Kpc, indicating that GPS and CSS sources must decline in luminosity at a faster rate than the classical 3CR doubles. The number count and linear size statistics used in these studies, are all averaged over a wide redshift range and only cover the brightest objects in the sky. However, as is shown in figure 2, in flux density limited samples the redshift distribution of GPS galaxies is significantly different from that of large size radio galaxies. This suggests that the interpretation of the number count statistics is not so straightforward.

The bias of GPS galaxies towards higher redshifts than large size radio galaxies provides an important clue about the luminosity evolution of radio sources. It implies that GPS galaxies are biased towards higher radio power than extended objects in flux density limited samples. If GPS and large size radio sources are identical objects, just observed at different phases pf the life cycle, their cosmological density evolution, e.g. their birth functions with redshift, should be the same. Since their lifetimes are short compared to the Hubble time, the redshift distributions of the GPS galaxies, and the objects they evolve to, should also be the same. The bias of GPS sources towards higher redshifts and radio powers therefore implies that their luminosity function must be flatter than that of large size radio sources. We argue that the luminosity evolution of the individual objects strongly influences their collective luminosity function, and propose an evolution scenario in which GPS sources increase in luminosity and large size sources decrease in luminosity with time. In the simplified case, in which source to source variations in the surrounding medium can be ignored, the luminosity of a radio source only depends on its age and jet power. Sources in a volume based sample are biased towards older ages and lower jet powers for populations of both GPS and large size sources. Low jet powers result in low luminosity sources. The higher the age of a large size source, the lower its luminosity, but the higher the age of a GPS source, the higher its luminosity. This means that for a population of large size sources the jet power and age bias strengthen each other resulting in a steep luminosity function, while they counteract for GPS sources, resulting in a flatter luminosity function.

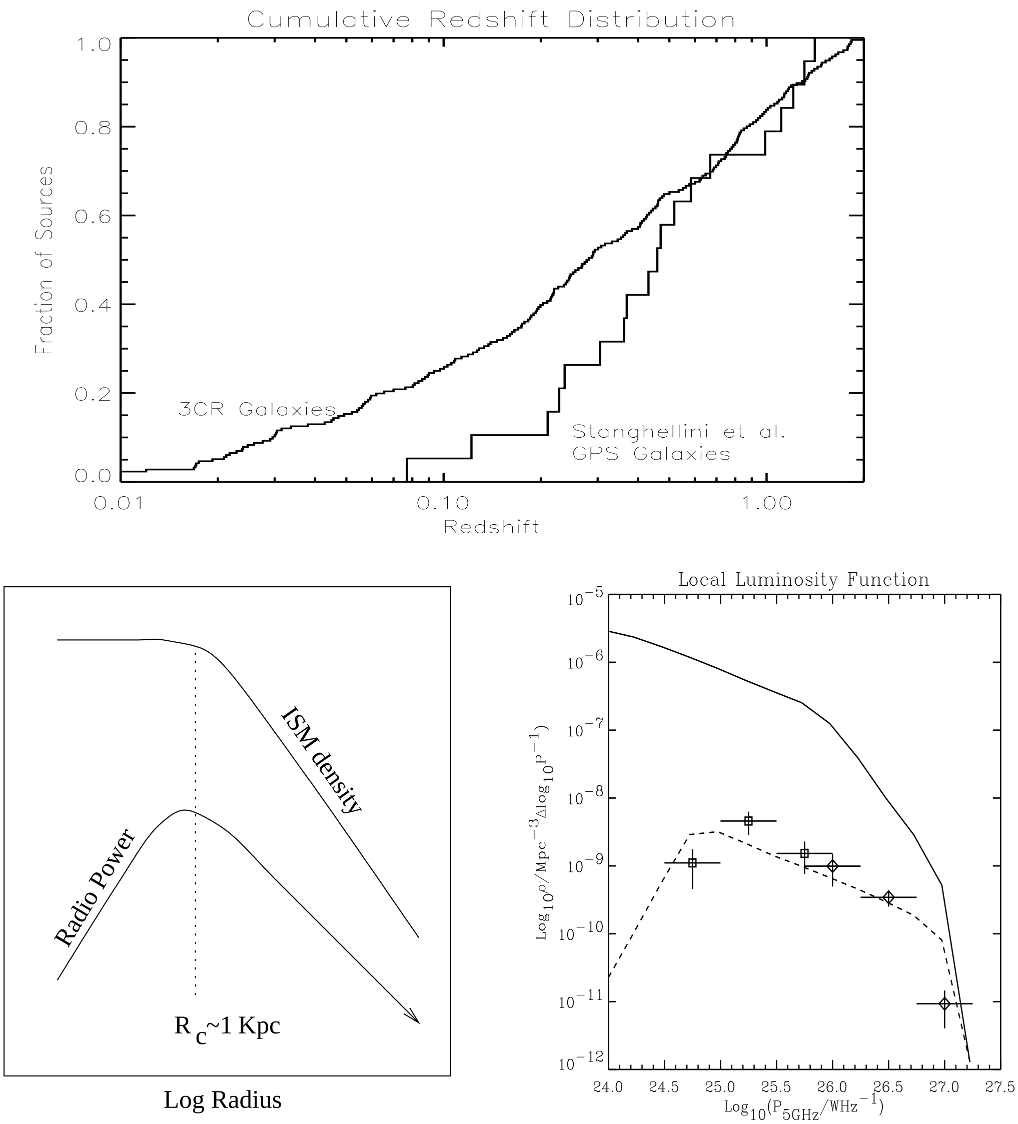

Fig. 2. (Top) The cumulative redshift distributions of GPS galaxies from the Stanghellini et al. sample (1998) and of 3CR galaxies. (Left) Schematic representation of the intra-galactic medium and the proposed luminosity evolution scenario for radio sources. (Right) The Local Luminosity Function of young radio sources derived from the faint and bright GPS samples. The solid and dashed lines represent simulated luminosity functions for extended and young objects respectively.

The luminosity evolution proposed is expected for a ram-pressure confined radio source in a surrounding medium with a King-profile density. In the inner parts of the King profile, the density of the medium is constant and the radio source builds up its luminosity, but after it grows large enough the density of the medium declines and the luminosity of the radio source decreases. An analytic model for radio sources with pressure confined jets has been developed by Kaiser & Alexander (1997). Interestingly, they showed that the properties of the bow shock and the surrounding gas force radio sources to grow in a

self-similar way, provided that the density of the surrounding gas falls off less steeply than $1/r^2$. X-ray observations of large nearby ellipticals show that their hot ISM follows a King distribution well, and have a core radius of typically 500-1000 pc (Trinchieri, Fabianno & Canizares 1986). Hence the predicted change in luminosity evolution can be expected to occur between the GPS and the CSS phases.

A way to test this luminosity scenario is to determine the local luminosity functions (LLF) for GPS galaxies and large size radio sources and compare it with simulated luminosity functions for a population of radio sources undergoing the proposed luminosity evolution. Unfortunately, only 4 GPS galaxies at $z < 0.2$ are present in the combined faint and bright GPS samples, too small a number to construct a LLF directly. However, since it can be assumed that the cosmological number density evolution for the young sources is the same as for old sources, the cosmological evolution of the luminosity function as derived for steep spectrum (eg. large size) sources (Dunlop & Peacock 1990) can be used to derive a LLF for young radio sources from the total faint and bright GPS samples. The combination of the bright and faint GPS samples is not straightforward, since they are selected in very different ways. This introduces a relatively uncertain correction factor of ~ 3 for the number densities derived from the faint sample. The result is shown in figure 2. A radio source population is simulated having random ages between 0 and 1000 time-units and jet powers over a range of 200, distributed with a powerlaw of -1.69, chosen to result in a slope of the luminosity function of large size sources at low radio powers of 0.69 in log, as determined by Dunlop & Peacock (1990). The objects younger than 1 time-unit are designated as GPS sources, and increase in luminosity with time, while the older sources decrease in radio luminosity. Assuming that the boundary between the GPS and large size phases is at 10^5 year, the age-limit of the large size radio sources in the simulation is 10^8 years. The resulting luminosity functions were scaled in such way that the break in the luminosity function of the large scale sources overlaps with what is found by Dunlop & Peacock for steep spectrum sources. Although the uncertainties are large and several free parameters enter the simulation, figure 2 shows that the shape of the LLF of GPS galaxies is as expected. This scenario is also consistent with the high number densities of GPS sources at bright flux density levels, since at the high luminosity end, the simulated LLF of GPS galaxies is only slightly lower than that of large size galaxies.

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